DYNAMICS OF COASTALLY TRAPPED DISTURBANCES DEDUCED FROM MM5 SIMULATIONS

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LONG TERM GOALS

We wish to advance the understanding of the interaction of a large-scale flow with complex terrain in the presence of a strongly stratified marine atmospheric boundary layer.

OBJECTIVES

We wish to carry out a detailed diagnosis of coastally trapped disturbances (CTD's) along the California coast, to document and understand dynamical mechanisms responsible for generating and maintaining such disturbances.

APPROACH

Because of limitations in observations offshore from and along the coastline, progress in understanding mesoscale, coastal phenomena is highly dependent on diagnostic studies performed with the aid of numerical simulations. Herein, we concentrate on simulations of observed events using a nonhydrostatic mesoscale model, capable of capturing the response of coastal flows to complex orography. Upon obtaining satisfactory simulations, the internal dynamical consistency of the model can be exploited to understand the chain of events that leads to a mesoscale vortex and coastal surge.

The numerical model used is the PSU/NCAR mesoscale model (MM5, Grell et al., 1994). The model is nonhydrostatic and employs grid nesting to achieve locally high resolution. Simulation of coastally trapped disturbances requires at once the proper treatment of synoptic scale motion, along with adequate representation of local terrain effects coupled with the shallow marine

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boundary layer. These demands require local high resolution, but also long-time integrations to cover the life cycle of the coastal disturbances, which may be one or more days. Therefore, predictability of not only the small scale, but also the large scale becomes questionable. For the purposes of creating a numerical simulation which best represents the real atmosphere and therefore enhances our understanding of the real processes involved, large-scale data are continually inserted into the model in an effort to supply correct boundary conditions for the high resolution mesh necessary to capture the coastally trapped disturbance itself.

WORK COMPLETED

During FY'97, we completed simulations of two cases of observed coastally-trapped disturbances, the Catalina Eddy event of 26-30 June 1988 and the southerly surge of 10-11 June 1994. For the Catalina Eddy case, the MM5 was run first in a two-domain configuration with a coarse mesh of 60 km resolution and a fine mesh of 20 km resolution, covering a 72 hour period from 1200 UTC 27 to 1200 UTC 30 June. During this period, all available conventional data were inserted continually into the model in an effort to minimize drift of the large-scale flow away from reality. The resulting 20 km simulation then provided initial and boundary conditions for a 6.67 resolution simulation, covering the same 72 hour period. The simulation utilized 45 layers in the vertical.

For the June 1994 case, a similar model configuration was was used as in the June 1988 case, except that the 60 km, 20 km and 6.67 km resolution domains were run simultaneously (a possibility only because the domains were smaller than for the Catalina Eddy simulation and therefore required less machine memory). The forecast was begun at 1200 UTC 9 June. Assimilation of various data was performed from 1200 UTC 9 June to 0000 UTC 10 June. The global NCEP analysis was used to perform nudging on the 60 km domain; standard surface observations and soundings, as well as NOAA/ETL profilers and acoustic sounder information (in collaboration with Dr. Ola Persson of NOAA/ETL) were incorporated into the data assimilation on the 20 km and 6.67 km domains. The method of assimilation was Newtonian relaxation (Stauffer and Seaman, 1990). From 0000 UTC 10 to 1200 UTC 11 June, a free forecast was run on the 6.67 km-resolution domain, but data assimilation continued on the coarser domains to maintain an accurate representation of the larger-scale flow. Tests were performed to assess the effect of excluding various data types. Other tests, to be reported on below, either the diurnal cycle, the surface drag, or both. These tests were designed to examine whether there should be a diurnal variation in the formation of southerly surges, and whether the flow reversal was related to viscous generation of vorticity in airflow past complex terrain.

RESULTS

Based on our simulations, the Catalina Eddy may be best described as part of a mountain wake, shed as flow past topography becomes stronger and more stably stratified at night. Importantly, as noted by Mass and Albright (1989), the synoptic-scale flow becomes more northerly or even northeasterly during these events than one sees under climatological conditions (Fig. 1). This allows the wake to be advected out over the bight region south of Pt. Conception. The overall process is not a continuous growth of the eddy. Rather, during each night over the course of 3-4 days, eddies are shed from the mountain and advected with subsequently weaker and more northeasterly flow, such that the wake occupies most of the bight region eventually.

The surface wind and sea level pressure at 1200 UTC 30 June depict the eddy near its maximum areal extent, covering much of the bight region (Fig. 1).The corresponding potential vorticity (PV) and winds on the 298 K isentropic surface at 1200 UTC suggest a rather complicated vortex shedding process (Fig. 2). That the eddy circulation is intimately associated with the positive PV anomaly is evident from a vertical cross section (Fig. 3).

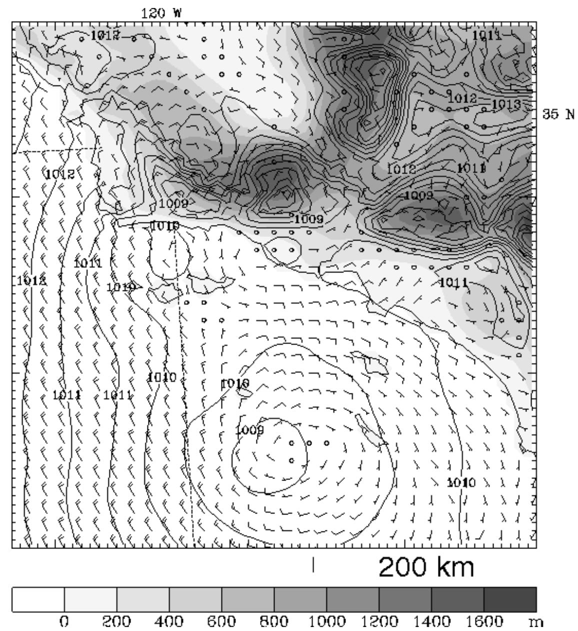

Figure 1. Sea-level pressure (solid lines, 1 mb interval) and winds at the lowest model level for 1200 UTC 30 June, a 72 hour forecast. Gray scale indicates terrain elevation.

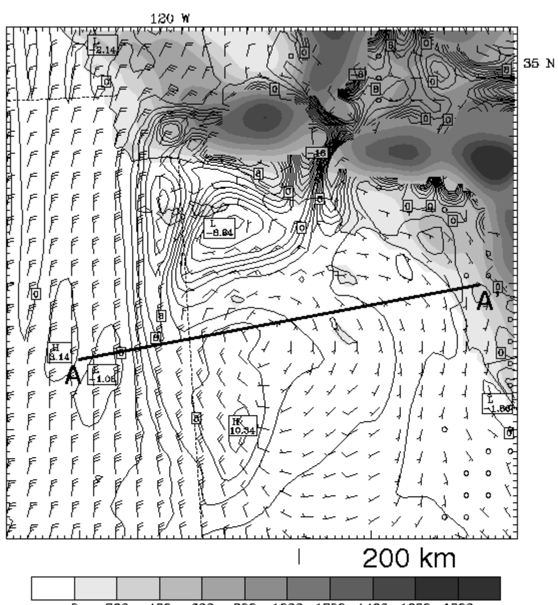

Figure 2. As in Figure 1 but for PV and winds on the 298 K isentropic surface.Contour interval is 1 PVU.

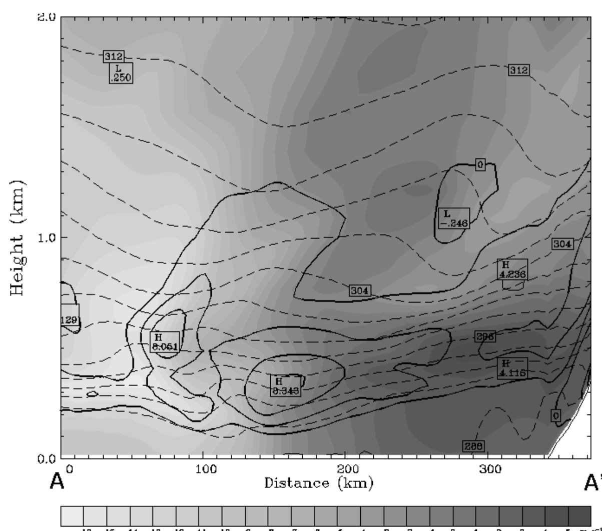

Figure 3. Cross section (see Fig. 2) of PV (solid, 2 PVU interval), potential temperature (dashed, 1 K interval) and normal wind component (shaded) for 1200 UTC 30 June.

The source of the vorticity has not been verified conclusively, but the fact that significant PV anomalies are generated implies that dissipative processes are at work. We note that vorticity and PV anomalies, both positive and negative, are produced. The ultimate dominance of a cyclonic eddy is expected based on (a) the shape of the mountains north of the bight, which to northerly flow look like the right half of a symmetric obstacle and (b) the Coriolis force, which favors the persistence of cyclonic vortices on the mesoscale.

The southerly surge event of 10-11 June 1994 has proven much less predictable than the Catalina Eddy event. Even though the synoptic scale flow was critical for producing extensive lee troughing and moving the northerlies further offshore, there was still an important role played by flow features on scales of 100 km or less in determining the detailed timing, strength and northward progression of the surge.

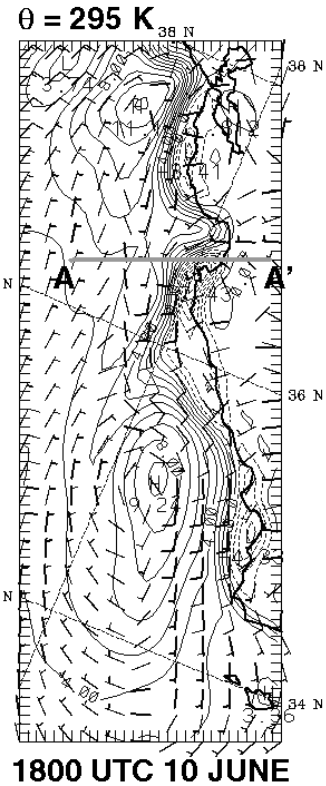

Figure 4. PV and wind on the 295 K isentropic surface at 1800 UTC 10 June, 1994. Contour interval is 1 PVU.

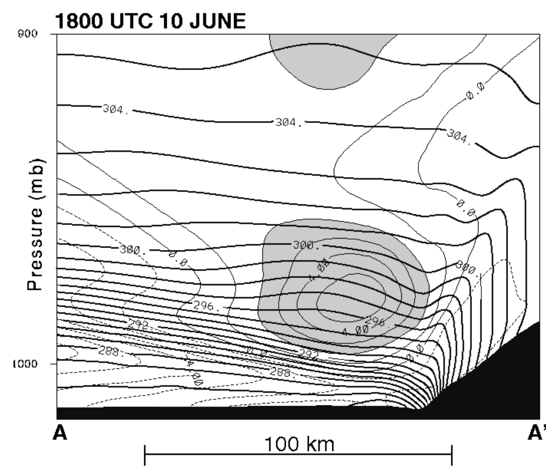

Figure 5. Cross section (see Fig. 4) of meridional wind (thin lines, 1 m/s interval) and potential temperature (heavy solid lines, 1 K interval). Areas of southerly winds > 2 m/s are shaded.

The MM5 simulation of this case closely resembles the results obtained by Thompson et al. (1997), in terms of the timing, strength and northward push of the coastal southerlies (Fig. 4). In agreement with their modeling results and observations (Ralph et al., 1997), the furthest northward push occurred within the marine layer, not at the surface (Fig. 5). One also notes that the southerlies occur on the east side of an elongated anomaly of PV. Preliminary calculations suggest that a significant portion of the southerly surge is part of the rotational flow, and not associated with a Kelvin wave or gravity current. This is a result similar to that obtained by Persson (1996). As in the Catalina Eddy case, the important vorticity and PV appear to begenerated by dissipative processes in flow past coastal terrain.

IMPACT

Based on our numerical simulations, which appear to capture the basic behavior of the observed systems we study, the generation of coastal wind reversals along the West Coast is dominated by local topography. The importance of these coherent structures, being long-lived and perhaps dynamically balanced, adds a twist on previous interpretations of CTD's in terms of Kelvin waves, bores or gravity currents. Very near the terrain, there is no doubt that highly ageostrophic, irrotational motions determine the local behavior. But understanding how these motions might originate requires understanding the meso-β effects of terrain.

In general, these effects fundamentally involve boundary layer mixing. Our calculations suggest that the details of the boundary layer significantly modulate the terrain response, as evinced by its diurnal character: vortices are shed primarily at night. Tests in which the surface drag was removed (for the June 1994 case) were inconclusive, as a well-defined southerly surge still formed, but was also accompanied by significant PV anomalies, apparently generated by numerical truncation error instead of explicit mixing.

TRANSITIONS

RELATED PROJECTS

This project has benefited from collaboration with Professor Clifford Mass at the University of Washington, Dr. Ola Persson, NOAA/ETL and Drs. Richard Rotunno, Joseph Klemp and William Skamarock at NCAR.

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